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Decision Support System (DSS) for Hierarchical Allocation of Resources and Tasks for Disaster Management

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Abstract After the occurrence of a natural disaster, it is of paramount importance to take efficient measures to reduce the casualties and damage of infrastructure. Resource allocation is a generic problem of assigning available resources to the affected areas to cope with the devastation caused by the disaster. To mitigate the deadly effect of a natural disaster, different resources are essential at the emergency sites. Disaster response activities also need the assignment of various critical tasks to be carried out by different emergency workers at the local level. The individual emergency locations convey their demands of resources and required services to the higher-level authorities. Depending on availability, the higher-level authority allocates resources through successive lower levels to the emergency sites. This paper proposes a model for the hierarchical flow of different resources during disaster management in the Indian context from the top-level authority to the lower levels. This hierarchical architecture also incorporates the allocation of different essential tasks at the ground level to reduce the effect of a natural disaster locally.

Keywords Disaster Response · Resource Allocation · Task Allocation · Decision Support System · Hierarchical Allocation · Flood Management

1 Introduction

The casualties and economic losses caused by a natural disaster necessitate immediate response and recovery activities to initiate. In the post-disaster scenario, the localities affected by the disaster require various critical resources and services to mitigate the impact of the disaster that arises locally. The disaster management authority allocates available resources among emergency sites based on the requirement of resources subject to resource availability. Decision-making, during or after a natural disaster, can be very complex, considering its dynamics and severity. To automate the decision-making process by the authorities, depending on various ground truth parameters and useful data, a computer-based decision support system (DSS) can be highly effective for a quick and unbiased response towards the emergency sites. A DSS system can support the disaster authority with limited experience to take fast decisions based on a model developed from previous experiences. Decision support system for disaster management is reported in various literature by Wallace and De Balogh (1985); Horita and de Albuquerque (2013); Sati (2015); Liashenko et al. (2019); Moehrle and Raskob (2019). Newman et al. (2017) introduces a detailed review of decision support systems for natural hazard risk reduction. Zhou et al. (2018) provides an overview of the emergency decision-making theory and methods of natural disasters from the methodological perspective. Aifadopoulou et al. (2018) develop a web-based, GIS-enabled intelligent DSS to implement protection and management measures that optimally address the transport networks and infrastructures. Zamanifar and Hartmann (2021) present a systematic case study of structured framework to suggest decision attributes for disaster recovery planning of transportation networks. In general, DSS are developed for different phases of disaster management: prevention, preparedness, response, and

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recovery. This paper mainly focuses on developing a DSS system for resource allocation in the response stages of disaster management.

Decision support systems for resource allocation during a disaster are reported in the past literature (Kondaveti and Ganz, 2009; Park et al., 2014). Kondaveti and Ganz (2009) develop a decision support system for resource allocation in three phases; clustering the victims, resource allocation, and resource dispatching. Hashemipour et al. (2017) describe a framework based on a multi-agent coordination simulation-based decision-support system. The system helps response managers in a community-based response operation who want to test and evaluate all possible team design configurations and select the highest-performing team. Wang and Zhang (2019); Li et al. (2019) use an agent-based framework for the distribution of resources during a disaster scenario. Authors like Othman et al. (2017) propose a multi-agent-based architecture for the management of emergency supply chains (ESC), in which a DSS states and solves the scheduling problem for the delivery of resources from the supply zones to the crisis-affected areas. Sepúlveda et al. (2018); Sepúlveda and Bull (2019) report model-driven DSS for distribution of supplies in the situation of natural disasters.

Resource allocation in an emergency scenario is reported in various literature (Arora et al., 2010; Worby and Chang, 2020; Fiedrich et al., 2000; Lechtenberg et al., 2017). (Wang et al., 2020) present a multi-objective cellular genetic algorithm (MOCGA) for resource allocation in a post-disaster scenario. In (Rolland et al., 2010), a project management and scheduling problem to assign personnel to different disaster locations is formulated and solved by a hybrid meta-heuristic algorithm. A vehicle scheduling and routing problem during an emergency is modeled with integer linear programming models in (Faiz et al., 2019). A post-disaster resource allocation framework is proposed by combining agent-based modeling and reinforcement learning (Sun and Zhang (2020)). Agent-based modeling is used for resource allocation to incorporate the relief urgency and behavior of different aid carriers and providers (Das and Hanaoka (2014)). Effective resource allocation is performed after the computation of the relief urgency index using qualitative and quantitative parameters related to allocation and distribution. Resource allocation during a simultaneous disaster is reported using stochastic optimization techniques (Doan and Shaw (2019)). In (Majumder et al., 2019), a resource allocation problem in a limited resource scenario is formulated as a non-cooperative game where the Nash equilibrium gives the solution of the game, and a mathematical analysis shows that pure strategy Nash equilibrium always exists for the game. The authors in (Nagurney et al., 2016) present a supply chain for disaster relief operation by multiple nongovernmental organizations (NGOs) using a generalized Nash equilibrium-based game-theoretic framework. In this work, the NGOs compete with each other for financial funds from the donors, and then they supply relief materials to the disaster victims. Wang et al. (2019) propose a multi-period allocation of scarce resources in a post-disaster scenario while maintaining equity.

As most of the administrative structure of the government system is hierarchical in nature, the resource allocation framework should include the hierarchical structure of resource allocation and distribution. In general, resources are propagated from the top-level authority to the emergency sites through various intermediate levels. The hierarchical approach of resource distribution is reported in Ghaffari et al. (2020); Widener and Horner (2011); Özdamar and Demir (2012). Ghaffari et al. (2020) propose resource distribution over the supply chain network with multiple customers using particle swarm optimization and mixed-integer programming. In (Widener and Horner, 2011), a facility location problem is modeled using a hierarchical structure during hurricane relief distribution. Özdamar and Demir (2012) propose a vehicle routing model that aims to minimize the travel time and incorporates the idea of a hierarchical cluster. A priority-based hierarchical model is discussed in (Liberatore et al., 2014) for the distribution of emergency goods in disaster logistics.

In this paper, we propose a hierarchical resource and task allocation architecture for the allocation of resources during floods among the different disaster control centers. In general, resources are allocated from top-level to bottom-level control centers based on the requirement of resources at various emergency sites. Different resources can be disaster management teams, UAVs, transport vehicles, relief materials, medical teams, etc. Resource allocation at the upper level is performed based on the total available resources, resource requirements, and priority of next-level crisis locations. The crisis locations need various resources to conduct disaster response tasks. The priorities of these crisis locations are decided based on their population density, disaster-affected area, the level of disaster, the static and dynamic conditions of the road network, etc. At the bottom level, apart from allocating the relief supplies to different emergency sites, many different tasks like search and exploration, evacuation operations, etc., are also executed. We developed a task allocation architecture, where all tasks, including resource allocation, could be handled at the block level through task allocation. The task allocation is performed based on the requirement of resources for the task, priority of the task, task location, and time required to reach the task location. We consider the administrative structure of India for the development of hierarchical allocation architecture. In the Indian context, resources are allocated from the state-level (SCC) to block-level (BCC) through district level (DCC), and rescue operations are directly performed at the block level as per the requirement of the emergency sites (ES).

The remainder of this paper is organized as follows. Section 2 describes the general formulation of resource and task allocation architecture. The proposed architecture in the context of the flood is described in Section 3. Section 4 and Section 5 describe the resource and task allocation algorithm framework. A detailed example of resource and task allocation is presented in Section 6. The software framework of the proposed architecture is described in Section 7. Concluding remarks are given in Section 8.

2 Resource and Task Allocation Architecture

In this section, a detailed resource and task allocation framework during a disaster is discussed. In general, disaster management authorities allocate resources among the affected units based on resources available from the upper administrative level and demand requirements at the lowest administrative level. Here, we consider affected units are the crisis locations, and an individual affected unit is under the same administration, that is, under the same state or same district or same block. Emergency response is usually a hierarchical process with the interaction between various agencies, as mentioned in (Salmoral et al., 2020) among many other similar works. In our work, we identify a three-layer hierarchical framework as depicted in Fig. 1. The three hierarchical layers considered are Top-Level Control Centre (TCC), Mid Level Control Centre (MCC), and Low-Level Control Centre (LCC). Higher authorities like TCC allocate resources to lower levels based on disasters such as flood map/road network map, demand of resources, and resource availability. Resources are distributed to affected people at the very lower level, and information about the status of the road, water level, and many other parameters are passed to the higher authority. At the LCC level, apart from resource allocation, rescue operations such as surveillance and survivor detection are performed.

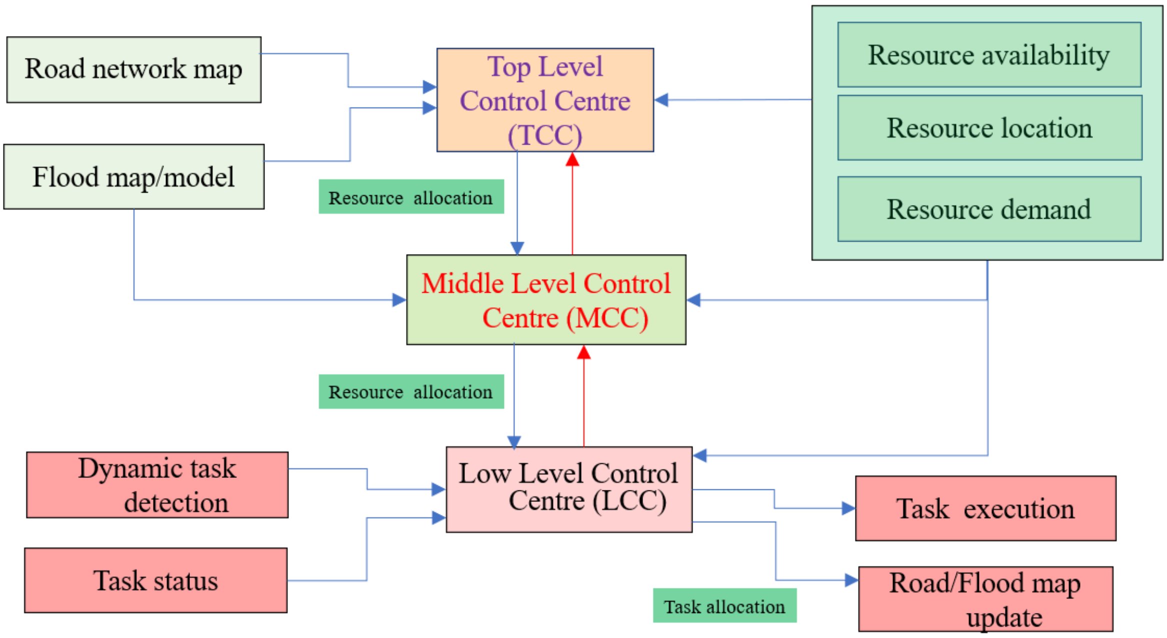


Fig. 1 Hierarchical architecture for a disaster scenario

Any resource allocation architecture in a disaster scenario should be scalable to large-scale operations and should be flexible to accommodate varying demand and supply conditions. The resource allocation framework should also be able to include a multi-layer organizational structure to handle a large-scale disaster scenario. The proposed framework considers the resource allocation and other tasks related to rescue operations, such as search and rescue, in an integrated hierarchical framework. The different hierarchical layers can be different based on the administrative structure of the country. The overall architecture takes input from the user about resources and demands, specifications of the affected units and generates the final resource allocated to each affected unit.

A typical three-tier hierarchical resource allocation scenario is shown in Fig. 2. The resource pool is generally controlled by the top-level authority from which the supply chain continues up to the emergency sites. When a natural disaster strikes a huge area in a state, the emergency locations (ES) convey their respective demands of resources and the level of crisis to the LCC. The request of resources from different LCC get added up and conveyed at the MCC. Similarly, the resources required of different MCC are considered in the TCC. Resource allocation from the uppermost level TCC to the next level MCC is performed based on the total available resources, resources requirements, and priority of affected units. The priority of each affected unit is decided based on the population density, disaster-affected area, the level of disaster, the static and dynamic conditions of the road network, etc. The same principle applies to the allocation from MCC to the LCC level at the bottom.
At the LCC, the overall tasks involve relief supply and evacuation, search, and rescue, survivor tracking, among many other tasks. These tasks can be dynamic or static. Tasks such as exploring an area are considered static since the object of interest and its location do not change with time. On the other hand, tasks such as survivor tracking are considered dynamic tasks since the survivor may move and change their location, or the number of survivors can change with time. At LCC, the overall work related to disaster is performed in a systematic task allocation framework to handle critical tasks in a resource-constrained scenario. The task allocation is performed based on requirement, priority, task location. In Fig. 2, LCC-ij denotes the j^{th} LCC under i^{th} MCC. Similarly, ES-ijk means the k^{th} emergency site which comes under the j^{th} LCC of i^{th} MCC.

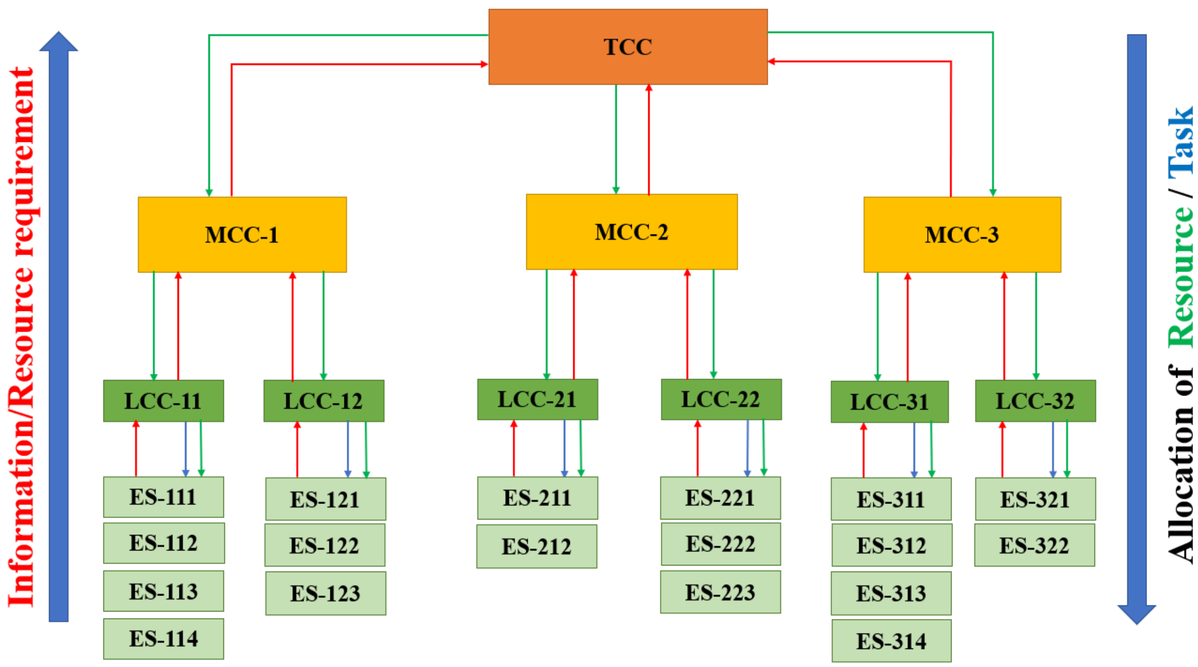


Fig. 2 Block diagram for resource and task allocation

3 Flood management

The proposed hierarchical framework is developed for relief and rescue operations during a flood scenario. The detailed architecture is shown in Fig. 3. In the case of flood scenarios, different resources are disaster management teams, Unmanned aerial vehicles (UAVs), transport vehicles, relief materials, and medical teams. The different tasks such as search and rescue operations, evacuation, and survivor tracking are performed at local levels. The requirement of the different resources of different units is processed to obtain the total requirement. The authority considers both prior and current information about the immediate lower-level units to decide the allocation matrix at each level. In the case of TCC, the prior information of MCC includes population, disaster handling capability, existing resources, etc., whereas the current information is level of devastation, affected flooded area, and requirement of resources. At the lower level, resource allocation is performed considering more detailed information about the affected units. At the MCC level, the prior information can include demography and the existing supply chain. At this stage, the status of the road network and water level of different units are also included for arriving at the allocation matrix. The predicted information about road networks and water level can also be considered for the decision-making process. At the lowest level, different tasks are performed based on the priority of the task and the proportion of relief materials are decided based on the population, demography, economic level, and road network of the emergency sites.

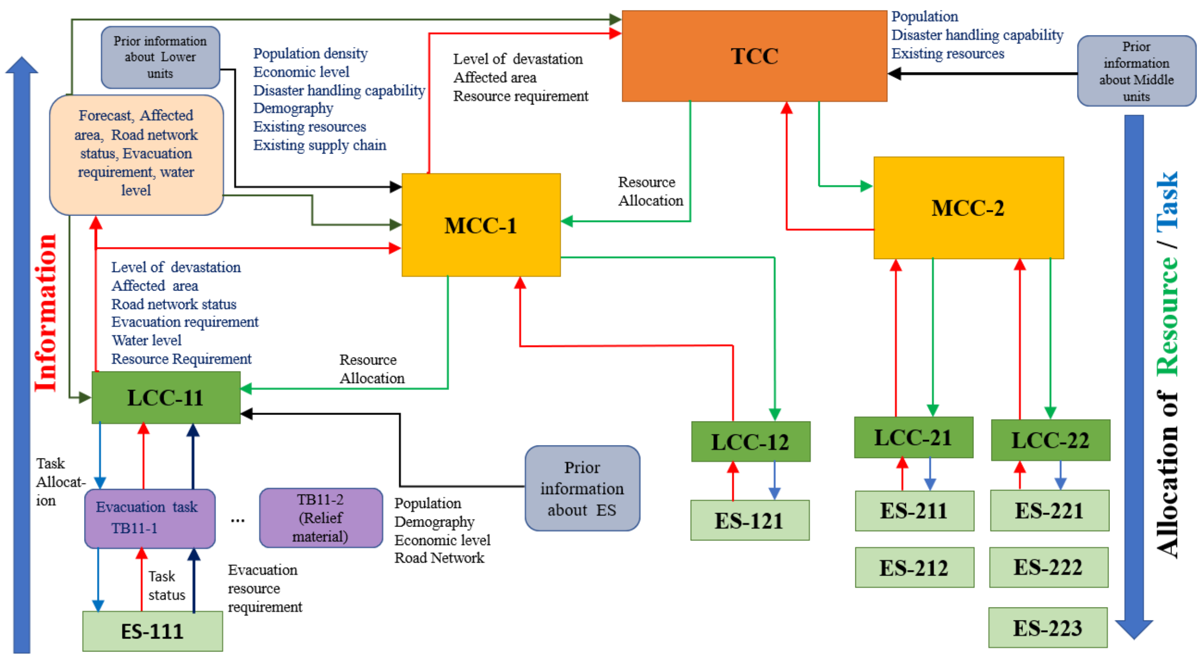


Fig. 3 Resource and task allocation architecture in case of flood scenario

4 Resource allocation

In this case, we have discussed the resource and task allocation architecture for a three-tier system. The proposed formulation can be extended to a multi-layer architecture. We consider a resource allocation formulation for the three-tier architecture where TCC allocates to different MCC units and each MCC unit allocates to different LCC units.

Let $R_1^T, ..., R_n^T$ be different resources available to TCC and it needs to be allocated to m different MCC units, say, M_1, ..., M_m. The requirement of i^{th} MCC for the j^{th} resource is R_{ij}^M. Let the weightage of each of the MCC be decided based on various factors such as population density (ρ), disaster-affected area (a) and level of disaster (γ). Then weightage (p) can be expressed as function h with argument as ρ, a, γ, etc.

$$p = h(\rho, a, ..., \gamma) \tag{1}$$

Let p_i^M be the weight of i^{th} MCC and there are η different factors which affect the allocation at TCC level. The value of k^{th} factor of i^{th} MCC unit is f_{ik}. The weight of k^{th} factor is w_k and $\sum_{k=1}^{\eta} w_k = 1$. Then, weight of i^{th} MCC unit related to k^{th} factor is,

$$p_i^M = \sum_{k=1}^{\eta} \frac{w_k f_{ik}}{\sum_{i=1}^{m} f_{ik}} \tag{2}$$

Then, the resource allocation matrix of j^{th} resources for the i^{th} MCC is as follows:

$$W_{ij}^M = \frac{p_i^M R_{ij}^M}{\sum_{i=1}^{m} p_i^M R_{ij}^M} \tag{3}$$

Resource allocated at the TCC level is the maximum value of the quantity of available resources and total requirement from different MCC units. The allocation of j^{th} resource at the TCC level is calculated as follows:

$$A_j^T = \min(R_j^T, \sum_{i=1}^{m} R_{ij}^M) \tag{4}$$

Then, the availability of the j^{th} resource for the i^{th} MCC is calculated as follows.

$$F_{ij}^M = A_j^T W_{ij}^M \tag{5}$$

Let us consider that i^{th} MCC has l LCC units and weight of the k^{th} LCC unit are obtained as p_{ik}^L and the requirement of j^{th} resource by k^{th} LCC is R_{kj}^{iL}.

Then, the allocation of the j^{th} resource at i^{th} MCC is calculated as follows:

$$A_{ij}^M = \min(F_{ij}^M, \sum_{k=1}^{l} R_{kj}^{iL}) \tag{6}$$

Let, the weightage of k^{th} LCC of i^{th} MCC unit be p_{ik}^L and there are g different factors which affect the allocation at MCC level. The value of r^{th} factor of k^{th} LCC of i^{th} MCC unit is f_{ikr}. The weight given to r^{th} factor is ω_r and $\sum_{r=1}^{g} \omega_r = 1$. Then, the weight of k^{th} LCC unit related to r^{th} factor is,

$$p_{ik}^L = \sum_{r=1}^{g} \frac{\omega_r f_{ikr}}{\sum_{k=1}^{l} f_{ikr}} \tag{7}$$

If the resource allocation matrix of j^{th} resources for the k^{th} LCC is

$$W_{kj}^{iL} = \frac{p_{ik}^L R_{kj}^{iL}}{\sum_{k=1}^{l} p_{ik}^L R_{kj}^{iL}} \tag{8}$$

then the availability of the j^{th} resource for k^{th} LCC unit of i^{th} MCC is

$$F_{kj}^{iL} = A_{ij}^M W_{kj}^{iL} \tag{9}$$

4.1 Allocation weightage

The weightage of different affected units at different level is determined based on different factors. From (2), it can be shown that sum of weights of each MCC is 1.

$$\sum_{i=1}^{m} p_i^M = \sum_{i=1}^{m} \sum_{k=1}^{\eta} \frac{w_k f_{ik}}{\sum_{i=1}^{m} f_{ik}} = \sum_{k=1}^{\eta} \sum_{i=1}^{m} \frac{w_k f_{ik}}{\sum_{i=1}^{m} f_{ik}} = \sum_{k=1}^{\eta} w_k \sum_{i=1}^{m} \frac{f_{ik}}{\sum_{i=1}^{m} f_{ik}} \tag{10}$$

So, we can write,

$$\sum_{i=1}^{m} p_i^M = \sum_{k=1}^{\eta} w_k \tag{11}$$

Hence,

$$\sum_{i=1}^{m} p_i^M = 1 \tag{12}$$

Similarly, it can be shown that

$$\sum_{k=1}^{l} p_{ik}^L = 1 \tag{13}$$

As the sum of the weights is 1, the overall architecture is scalable for the multiple factors and the multiple numbers of units. The weights provided to different factors (w_k and ω_r) can be chosen based on previous experience with the disaster event.

4.2 Computation of demand based on forecast

The basic demand (D^b) from any unit is adjusted based on the forecast of disaster level and road network. The overall demand (D^o) for the allocation is calculated based on the basic demand and the excess demand considering the forecast information.

Let there be r forecasted parameters which affects the allocation. The value of the n^{th} parameter of a MCC unit is E_n. The relative criticality of the n^{th} parameter of the MCC unit is calculated as,

$$R_n = \frac{E_n}{E_n^{\max}} \tag{14}$$

where, $E_n^{\max}$ is the maximum value of the n^{th} parameter. The excess demand (D^e) of a resource is calculated as follows,

$$D^e = \left(\sum_{n=1}^{r} \zeta_n R_n\right) D^b \tag{15}$$

where, ζ_n is relative weights provided to the different r parameters. If X percentage of basic demand is considered to accommodate the forecasted value, then,

$$\sum_{n=1}^{r} \zeta_n = \frac{X}{100} \tag{16}$$

The overall demand is calculated as,

$$D^o = D^b + D^e \tag{17}$$

Clearly, the maximum value of the overall demand is $(1 + \frac{X}{100})D^b$ and minimum value is D^b.

Let us consider an example where allocation at the TCC level is performed for two MCC units. Let the ratio of predicted disaster level to current disaster level and the ratio of predicted road network status to current road network status be used to calculate excess demand. It is assumed that the higher value of these parameters related to high severity and minimum value of the ratio is assumed to be 1. The basic demand of two MCC units and the parameters are shown in Table 1.

Table 1 Excess demand parameters

Name	**Basic demand**	**Disaster level ratio**	**Road network status ratio**
MCC-1	100	2	3
MCC-2	50	3	1

Let the value of X be 25, that is, a maximum of 25 % of basic demand is considered to accommodate the future scenario. The relative weights (ζ_n) of the parameters are considered as 0.15 and 0.10. The calculations of overall demand are presented in Table 2.

Table 2 Overall demand calculation

Parameters	**MCC-1**	**MCC-2**
Basic demand (D^b)	100	50
Relative criticality: R_1	0.66	1
Relative criticality: R_2	1	0.33
$\sum_{n=1}^{2} \zeta_n R_n$	0.199	0.183
Excess demand (D^e)	19.9	9.15
Overall demand (D^o)	119.9	59.15

4.3 Algorithm

The overall algorithm for resource allocation at TCC level is shown in Algorithm 1. The algorithm for resource allocation at MCC level will have similar equivalent steps.

Algorithm 1 Resource allocation at TCC level

Input: Available resources at TCC (R_j^T), Allocation factors of MCC units (f_{ik}), Weightage of allocation factors (w_k), Basic demand of MCC units, Parameters based on forecast (E_n), Relative weights of forecast parameters (ζ_n)

1. Calculate the relative criticality of parameters related to forecast: $R_n = \frac{E_n}{E_n^{\max}}$
2. Calculate the excess demand using the basic demand of MCC units using (15)
3. Calculate the overall demand: $D^o = D^b + D^e$
4. Input overall demand of each unit as desired resource requirement of each unit ((R_{ij}^M)).
5. Calculate the weight of each MCC unit using (2): $p_i^M = \sum_{k=1}^{\eta} \frac{w_k f_{ik}}{\sum_{i=1}^{m} f_{ik}}$
6. Calculate the weight allocation matrix for each resources related to each MCC: $W_{ij}^M = \frac{p_i^M R_{ij}^M}{\sum_{i=1}^{m} p_i^M R_{ij}^M}$
7. Calculation of maximum quantity of resources to be distributed by TCC: $A_j^T = \min(R_j^T, \sum_{i=1}^{m} R_{ij}^M)$
8. Calculate the available resources of each MCC: ($F_{ij}^M = A_j^T W_{ij}^M$)

Output: Allocation of affected units (F_{ij}^M).

5 Task allocation at LCC level

Every task is defined in terms of the requirement of different types of resources to accomplish the tasks. Considering flood, it is considered that each task will require Ground Vehicles (GV), Unmanned Aerial Vehicles (UAV), and Boats (B) to perform various tasks such as relief supply, surveillance, survivor tracking, etc. So, a task T_x which requires $T_{x_{GV}}$ number of GVs, $T_{x_{UAV}}$ number of UAVs and T_{x_B} number of boats is defined as,

$$T_x = [T_{x_{GV}}, T_{x_{UAV}}, T_{x_B}] \tag{18}$$

Similarly, the priority of each task is defined based on the criticality of the tasks involved. In this case, each task is classified as different sub-tasks as normal supply (NS), relief supply (RS), surveillance (SL), survivor tracking (ST), and critical supply (CS). The priority of task (T_x^p) is defined as a vector consisting of the priority of each sub-tasks,

$$P_{T_x} = [NS^p, RS^p, SL^p, ST^p, CS^p] \tag{19}$$

where, NS^p, RS^p, SL^p, ST^p, CS^p are the priority associated with the sub-tasks NS, RS, SL, ST, CS. Let the priority of the r^{th} sub-tasks are P_r^s. Then, for example, a task involving of sub-tasks consisting of surveillance and survivor tracking will have priority vector as follows,

$$P_{T_x} = [0, 0, P_3^s, P_4^s, 0] \tag{20}$$

Resources are allocated from the available resources to the tasks with high priority. The norm of the priority vector is used to sort the tasks. If the priorities are equal, the distance from the resource location to task location is considered for the resource allocation. The distance from the resource location to task location is calculated based on the available current network. This distance can be derived more accurately using the dynamic condition of the road network considering the predicted value of the water level and the extent of the damage. Algorithm 2 gives the details of the task allocation algorithm.

Algorithm 2 Task allocation at LCC level

Input: Available resources at LCC (F_{kj}^{iL}), Mission and relief requirement from emergency sites (ES), Tasks (T_x), priority of sub-tasks

1. Define the mission to be performed to meet the requirement of emergency sites.
2. Map the mission to different tasks (T_x) as per the resources required to perform the tasks: $T_x = [T_{x_{GV}}, T_{x_{UAV}}, T_{x_B}]$
3. Calculate the priority of tasks as per priority of sub-tasks: $P_{T_x} = [NS^p, RS^p, SL^p, ST^p, CS^p]$
4. Sort the tasks as per norm of priority vector.
5. Execute feasible tasks considering (F_{kj}^{iL}) with higher priority.
6. In case of equal priority, allocate resources based on the distance between the current location and task location.

Output: Sequence of tasks

6 Resource and task allocation case study

We have considered a resource allocation example for a disaster scenario due to a flood in India. The administrative structure for resource allocation is equivalent to TCC, MCC, and LCC: state-level, district-level, and block-level. Let us consider an allocation problem in which five resources are allocated at the state level to two districts with different priorities. Then the allocated resource to each district is further allocated to 3 individual blocks.

6.1 Weightage calculation

For simplicity, let us consider at the TCC level, the population density, disaster-affected area, and level of the disaster of the MCC units for weightage calculation of different units. The values of these parameters of District D_1 and District D_2 are shown in Table 3. The units of population density and disaster-affected area are per sq Km and Km^2 respectively. In the case of flood, the level of disaster can be classified at different levels (say, Level1 to Level 5, with Level 1 being least severe and Level 5 the most severe) based on the existing water level, road network status, and rainfall information. The classification for the disaster level has to be decided by the allocation authority based on the ground information from the lower-level units. In this case, it is assumed that high value is provided to high severity areas.

Table 3 Allocation factors at state level (TCC)

Name	**Population density** (f_{i1})	**Affected area** (f_{i2})	**Level of disaster** (f_{i3})
D1	100	100	5
D2	130	3000	3

The weights (w_k) of allocation factors f_{i1}, f_{i1}, and f_{i1} are assigned as 0.4, 0.4, 0.2, respectively. Higher weights provided to population density and disaster affected area as these two factors are directly responsible for the relief requirement of a given area. These factors can be decided by the allocation authority based on suitable judgement. Then, using (2), weightage of individual district is calculated. The weightage (p_i^M) of the districts D_1 and D_2 are obtained as 0.4 and 0.6, respectively. Clearly, any other factors such as disaster handling capability of the area can be considered in the same way as the level of disaster. Similarly, in order to include any qualitative factors, it first needs to be mapped to equivalent quantitative factor. Similarly, based on the different parameters of the blocks the weightage of each blocks are calculated. The weightage of different blocks under district D_1 and D_2 are p_{1k}^L and p_{2k}^L, respectively. The values of p_{1k}^L and p_{2k}^L are obtained as follows: $p_{11}^L = 0.4$; $p_{12}^L = 0.25$; $p_{13}^L = 0.35$; $p_{21}^L = 0.26$; $p_{22}^L = 0.48$; $p_{23}^L = 0.26$.

6.2 Resource availability and requirement

The quantity of available resources (R_j^T) at the state control center is given in Table 4. The overall resources requirement of the different blocks of district D_1 and district D_2 are mentioned in Table 5 and Table 6. The resources claimed by the individual units are modified using the excess demand considering the forecast scenario.

Table 4 Total resources

$\mathbf{R_1^T}$	$\mathbf{R_2^T}$	$\mathbf{R_3^T}$	$\mathbf{R_4^T}$	$\mathbf{R_5^T}$
300	100	150	300	150

Table 5 Resource requirement of different blocks of District D_1

Name	$\mathbf{R_{k1}^{1L}}$	$\mathbf{R_{k2}^{1L}}$	$\mathbf{R_{k3}^{1L}}$	$\mathbf{R_{k4}^{1L}}$	$\mathbf{R_{k5}^{1L}}$
D1_B1	40	50	80	100	20
D1_B2	10	20	50	15	40
D1_B3	20	40	60	90	100

Table 6 Resources requirement of different blocks of District D_2

Name	$\mathbf{R_{k1}^{2L}}$	$\mathbf{R_{k2}^{2L}}$	$\mathbf{R_{k3}^{2L}}$	$\mathbf{R_{k4}^{2L}}$	$\mathbf{R_{k5}^{2L}}$
D2_B1	20	50	60	100	30
D2_B2	10	40	30	15	20
D2_B3	20	40	40	90	80

The resource requirement of the block level (LCC) is accumulated at the district level, and the resource requirement of individual districts is accumulated at the state level. The individual resource requirement for each district is calculated after summation of the resources required for the individual block (shown in Table 7 and Table 8).

Table 7 Resources requirement of District D_1

Name	$\mathbf{R_{11}^{M}}$	$\mathbf{R_{12}^{M}}$	$\mathbf{R_{13}}^{\mathbf{M}}$	$\mathbf{R_{14}^{M}}$	$\mathbf{R_{15}^{M}}$
D1	70	110	190	205	160

Table 8 Resources requirement of District D_2

Name	$\mathbf{R_{21}^{M}}$	$\mathbf{R_{22}^{M}}$	$\mathbf{R_{23}^{M}}$	$\mathbf{R_{24}^{M}}$	$\mathbf{R_{25}^{M}}$
D2	50	130	130	205	130

6.3 Resource allocation

The output of the allocation algorithm at two iterations is presented here. The allocation of resources to districts from the state at different stages of allocation are shown in Table 9 and Table 10.

Table 9 Resources allocated to District D_1

Iteration	$\mathbf{A_{11}^{M}}$	$\mathbf{A_{12}^{M}}$	$\mathbf{A_{13}^{M}}$	$\mathbf{A_{14}^{M}}$	$\mathbf{A_{15}^{M}}$
1	57.93	36.07	74.02	120	67.60
2	70	36.07	74.03	120	67.60

Table 10 Resources allocated to District D_2

Iteration	$\mathbf{A_{21}^{M}}$	$\mathbf{A_{22}^{M}}$	$\mathbf{A_{23}^{M}}$	$\mathbf{A_{24}^{M}}$	$\mathbf{A_{25}^{M}}$
1	50	63.93	75.97	180	82.39
2	50	63.93	75.97	180	82.39

The allocation of resources to blocks from districts at different stages of allocation are shown in Table 11 and Table 12.

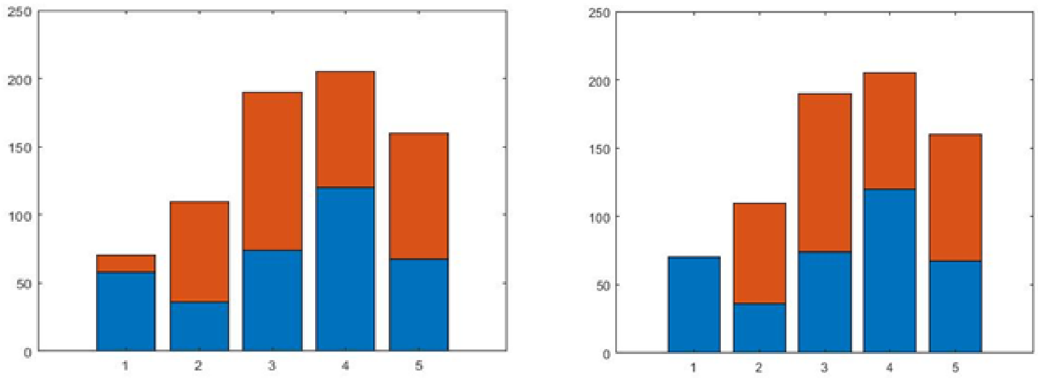
Table 11 Resources allocated to different blocks of District D_1

Iteration	**Name**	$\mathbf{F_{k1}^{1L}}$	$\mathbf{F_{k2}^{1L}}$	$\mathbf{F_{k3}^{1L}}$	$\mathbf{F_{k4}^{1L}}$	$\mathbf{F_{k5}^{1L}}$
1	D1_B1	36.35	18.50	36.17	63.79	10.20
2	D1_B1	40	18.50	36.17	63.78	10.20
1	D1_B2	5.67	4.62	14.12	5.98	12.76
2	D1_B2	8.95	4.62	14.13	5.98	12.76
1	D1_B3	15.90	12.95	23.73	50.23	44.64
2	D1_B3	20.0	12.95	23.73	50.23	44.64

Table 12 Resources allocated to different blocks of District D_2

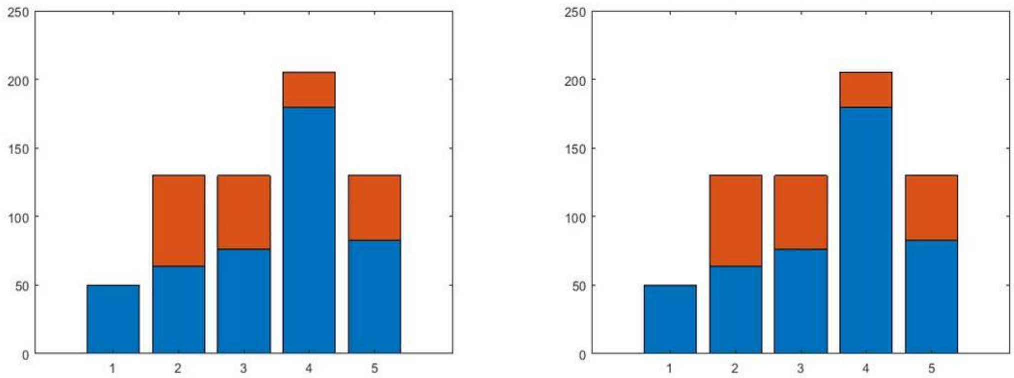
Iteration	**Name**	$\mathbf{F_{k1}^{2L}}$	$\mathbf{F_{k2}^{2L}}$	$\mathbf{F_{k3}^{3L}}$	$\mathbf{F_{k4}^{4L}}$	$\mathbf{F_{k5}^{5L}}$
1	D2_B1	17.10	19.51	29.33	82.68	16.82
2	D2_B1	20.0	19.51	29.33	86.84	17.02
1	D2_B2	10	28.81	27.07	15	20
2	D2_B2	10	28.81	27.07	15	20
1	D2_B3	17.10	15.60	19.55	74.41	44.86
2	D2_B3	20.0	15.60	19.55	78.15	45.37

The allocation of different districts and block at different allocation level is presented through bar diagram in Fig. 4, Fig. 5, Fig. 6, and Fig. 7. Here, the length of the bar presents the total demand, the blue color fraction presents the allocated amount, and the red color presents the deficiency in allocation.



(a) **Iteration 1** (b) **Iteration 2**

Fig. 4 Demand vs Allocation for District D_1



(a) **Iteration 1** (b) **Iteration 2**

Fig. 5 Demand vs Allocation for District D_2

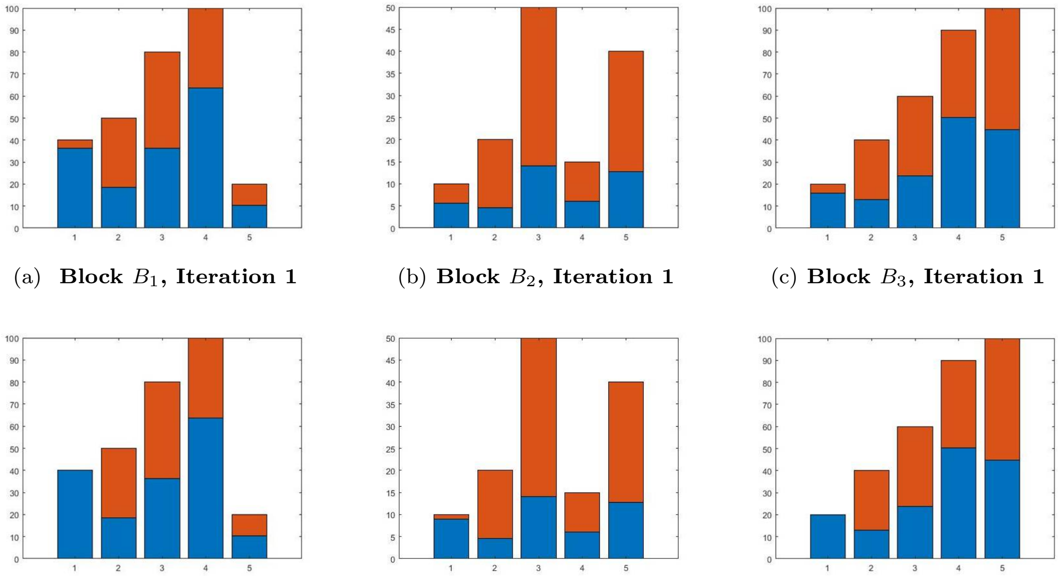
6.4 Task allocation

After allocation of resources at the TCC and MCC level, each LCC unit needs to distribute these resources at emergency sites. A task allocation scenario consisting of five tasks at the LCC level is presented in this section. Let us consider the case for block B_1 of district D_1 ($D1\_B1$) and the resources F_{k1}^{2L}, F_{k2}^{2L}, and F_{k3}^{2L} are related to numbers of GV, UAV and Boat, respectively. Each task related to rescue operations is initially divided into different sub-tasks and resources (GVs, UAVs, and Boats) required to perform each task is mentioned in Table 13. For example, in this case, task (T_1) is defined as $T_1 = [0, 2, 0]$. The five different sub-tasks are survivor tracking, relief supply, critical supply, surveillance, and normal supply. The priority associated with the individual sub-tasks is given in Table 14.

Table 13 Resources requirement of different tasks

Name	GV	UAV	Boat
T_1	0	10	0
T_2	15	0	20
T_3	20	5	15
T_4	0	5	5
T_5	5	0	0

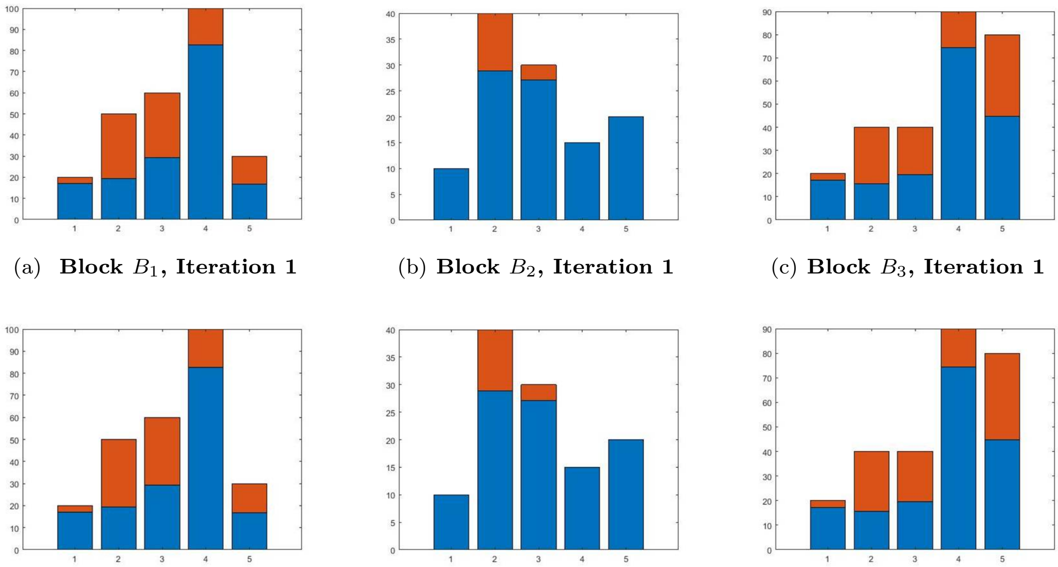
The priority vector of each task is decided based on its composition of sub-tasks and the priority involved with the individual sub-tasks (shown in Table 15). For example, the priority vector of task (P_{T_1}) is defined as P_{T_1}: [0,0,0, 200, 0].



(a) **Block B_1, Iteration 1** (b) **Block B_2, Iteration 1** (c) **Block B_3, Iteration 1**

(d) **Block B_1, Iteration 2** (e) **Block B_2, Iteration 2** (f) **Block B_3, Iteration 2**

Fig. 6 Demand vs Allocation of Block B_1 and Block B_2 of district 1



(a) **Block B_1, Iteration 1** (b) **Block B_2, Iteration 1** (c) **Block B_3, Iteration 1**

(d) **Block B_1, Iteration 2** (e) **Block B_2, Iteration 2** (f) **Block B_3, Iteration 2**

Fig. 7 Demand vs Allocation of Block B_1, Block B_2 and Block B_3 of district D_2

Table 14 Priority of different sub-tasks

NS^p	RS^p	SL^p	ST^p	CS^p
1	10	50	200	100

Tasks are sorted out using the norm of the priority vector, so in this case, the sequence of tasks are P_{T_1}, P_{T_3}, P_{T_4}, P_{T_2}, P_{T_5}. The actual allocation available at block B_1 of district D_1 from the resource allocation is shown in Table 16.

So, after the first level of allocation, the resource required to perform T_1, T_2, T_3 are available, so these tasks are executed. Although T_4 has higher priority than T_2, sufficient resources are not available to execute T_4. The resources related to F_{k2}^{1L}, that is, sufficient number of UAV is not available to perform the tasks T_4 along with T_1 and T_2. After the second level of allocation, sufficient resources are still not

Table 15 Priority of different tasks

Name	NS^p	RS^p	SL^p	ST^p	CS^p
P_{T_1}	0	0	0	200	0
P_{T_2}	0	10	0	0	0
P_{T_3}	0	10	0	0	100
P_{T_4}	1	0	50	0	0
P_{T_5}	1	0	0	0	0

Table 16 Actual allocation available of block B_1 of district D_1

Iteration	Name	$\mathbf{F^{1L}_{k1}}$	$\mathbf{F^{1L}_{k2}}$	$\mathbf{F^{1L}_{k3}}$	$\mathbf{F^{1L}_{k4}}$	$\mathbf{F^{1L}_{k5}}$
1	D1_B1	36	18	36	64	10
2	D1_B1	40	18	36	64	10

available to perform the next high-priority tasks T_4. So, the next high-priority tasks T_5, which can be allocated the desired resources, are performed. In summary, initially mission related to T_1, T_2 , T_3 are executed and after second level of allocation, task T_5 is also executed. Task T_4 can be executed only after receiving sufficient resources during future allocation. If the tasks are broken into smaller tasks, the utilization of allocated resources can be increased.

7 Software implementation

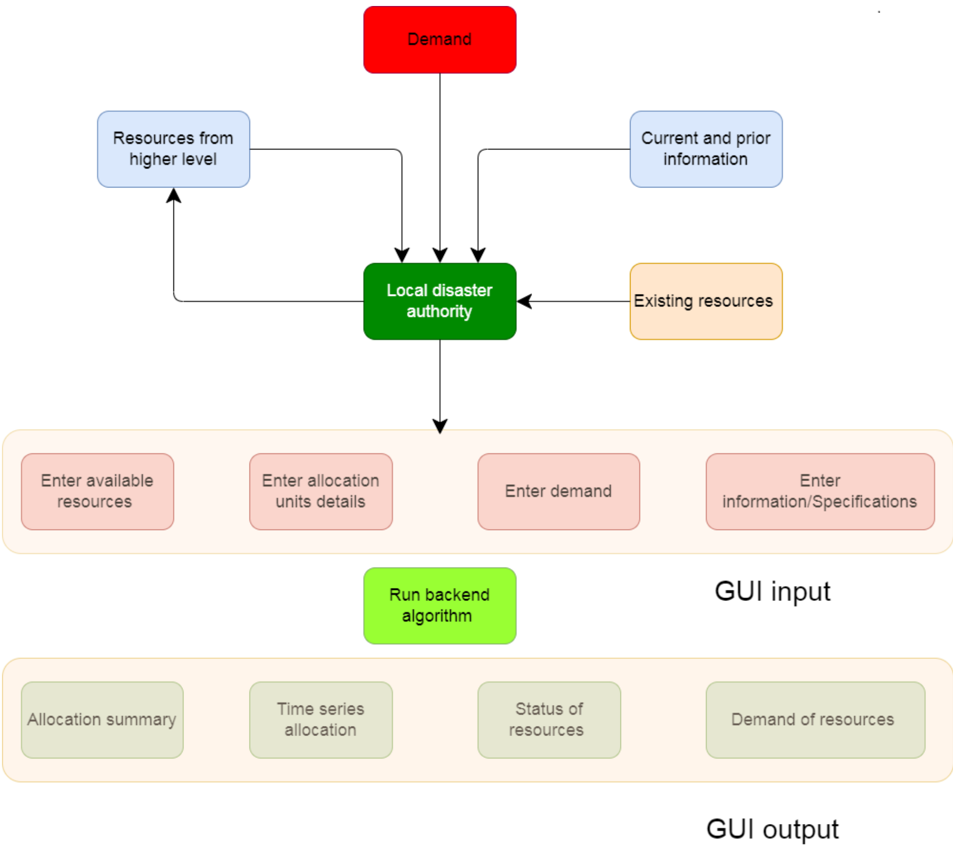


Fig. 8 Software framework

The proposed resource allocation architecture is implemented in a software framework. The inputs to the software framework are the existing resources and demands of the different units and their specifications. It outputs the resources to be allocated to each unit. The resources can be selected from the pre-defined database, and the user can also add a new resource. A typical software framework for resource allocation is shown in Fig. 8. The resource allocation software framework is integrated with a Graphical User Interface (GUI) using MATLAB for easy implementation at the ground level. Currently, the GUI is developed for five crisis locations and six factors; however, it is easily scalable to higher numbers of crisis locations/factors. In the "Home" tab of GUI (shown in Fig. 9). The backend program is run based on user-selected crisis location and the number of factors. Currently, a virtual allocation scenario is shown in the GUI for two districts of the Indian state of Kerala, namely Ernakulam and Alapuzha, and the factors considered are affected area, population density, disaster level, and disaster handling capacity (as shown in Fig. 9). In the "Specification" tab (shown in Fig. 10), the associated factors related to crisis locations need to be provided. The overall weights of each district are calculated through this tab, where there is a provision for the user to enter custom weights. The quantities of different resources available to the resource allocation authority are considered through the "Resources" tab in Fig. 11. The demands of individual crisis locations are entered through the "Demand" tab (shown in Fig. 12). Allocation of individual resources among the crisis location can be obtained as given in Fig. 13. The overall allocation of the individual crisis locations can be obtained through the "Area wise Allocation" tab. The allocation for Ernakulam and Alapuzha for the current scenario is shown in Fig. 14 and Fig. 15, respectively. The allocation summary through bar diagram can be obtained through the "Graphs" tab (as shown in Fig. 16).

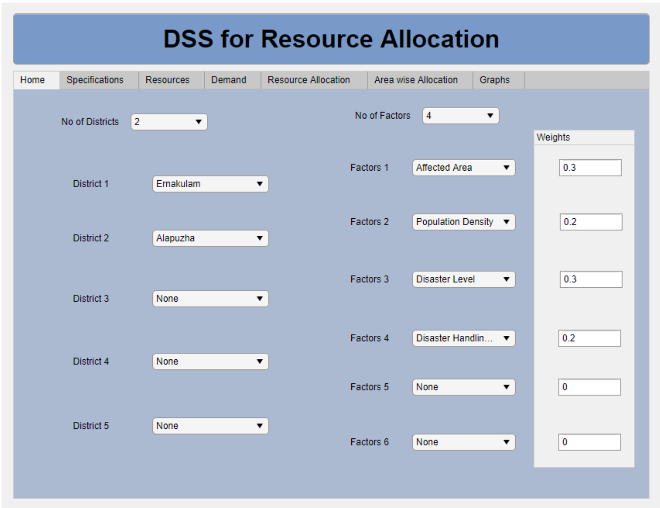


Fig. 9 "Home" tab for entering the affected districts, factors and associated wights for allocation

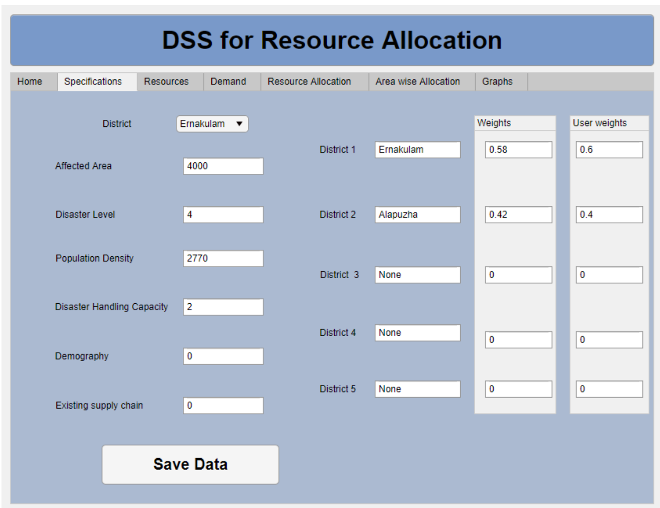


Fig. 10 "Specifications" tab

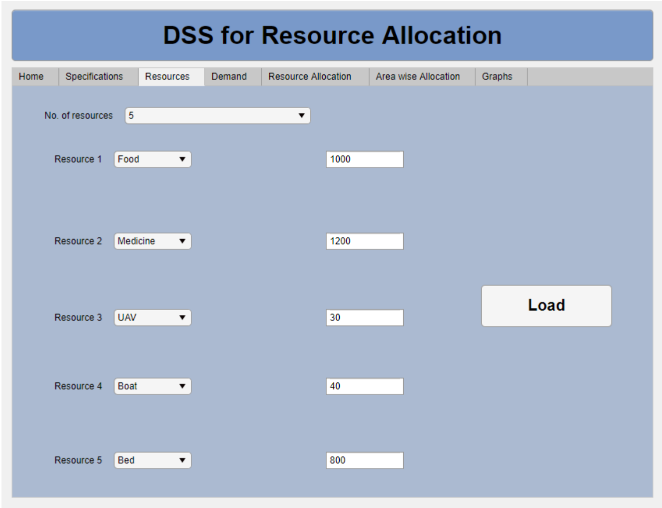


Fig. 11 “Resources” tab

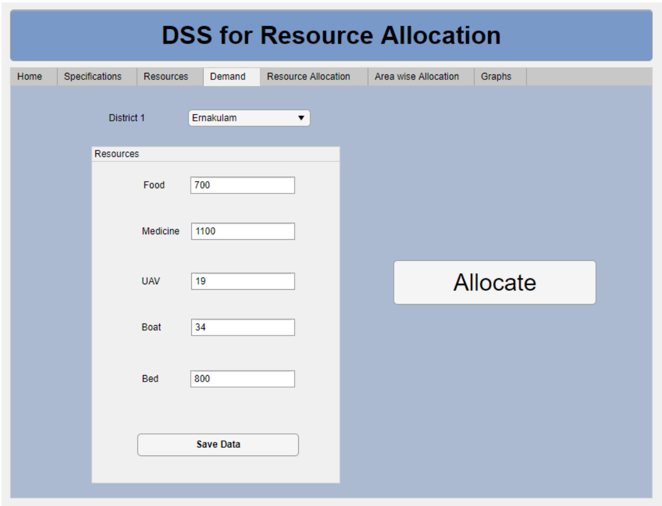


Fig. 12 “Demand” tab for entering the demand of crisis locations

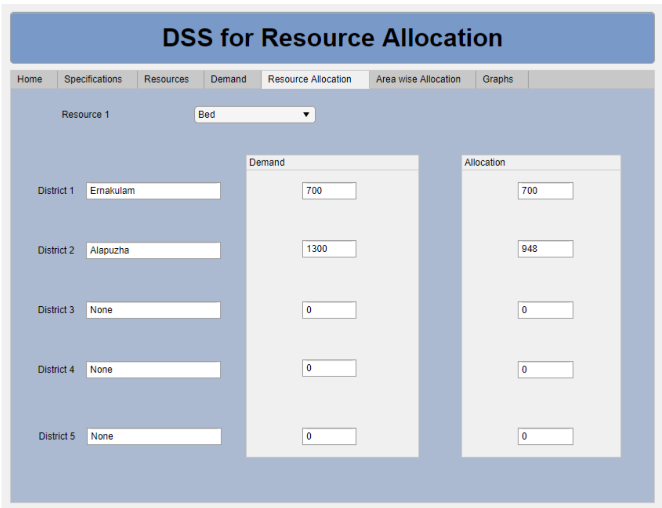


Fig. 13 “Resource Allocation” tab to obtain the allocation for a particular resource

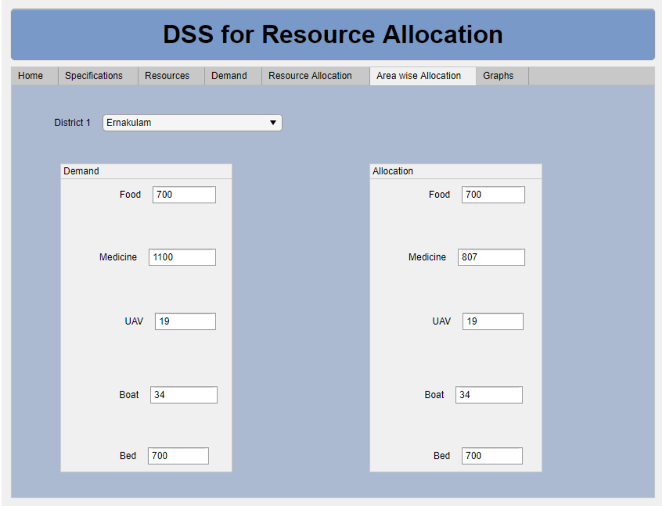


Fig. 14 Allocation for crisis location 1: Ernakulam

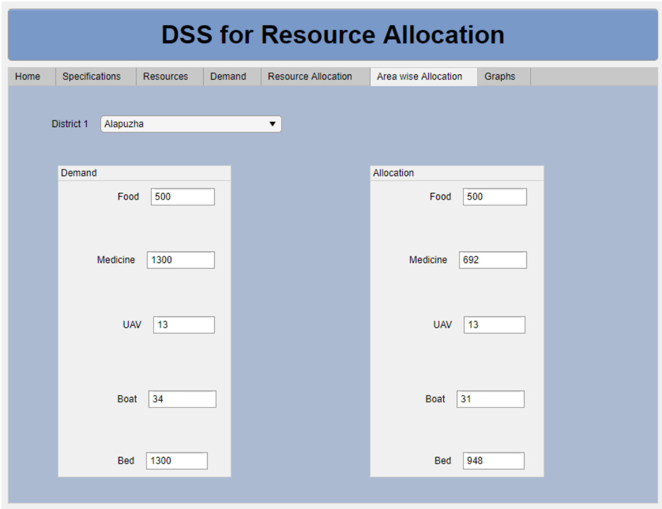


Fig. 15 Allocation for crisis location 2: Alapuzha

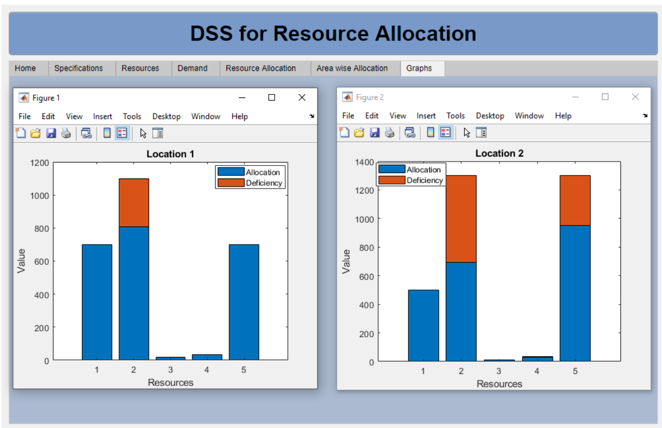


Fig. 16 “Graphs” tab: Allocation summary

8 Conclusions

This paper presents a hierarchical allocation architecture for resource and task allocation during a flood-like disaster scenario. The proposed architecture is developed considering the flow of resources from the hierarchical administration of the government in a real scenario. The allocation is performed based on the priority of the units based on the different factors such as population density, disaster level, etc.. The proposed framework is scalable to accommodate different factors affecting allocation and different levels of multiple hierarchical units. An example scenario of resource and task allocation for flood management considering the administrative structure of India is studied. The proposed framework can be applied to resource allocation during other similar large-scale natural disasters; however, the factors for priority determination will be different. Future work includes the development of a software system deployable for a large-scale natural disaster scenario for resource and task allocation.

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Declaration of conflicting interests

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Data availability statement

The authors declare that the data supporting the findings of this study are available within the article.

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